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MOTION OF THE SOURCES FOR TYPE II AND TYPE IV
RADIO BURSTS AND FLARE-ASSOCIATED INTERPLANETARY DISTURBANCES

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**Short Title:** The Speeds of Flare-Associated Disturbances

Abstract

Shock waves are indirectly observed as the source of type II radio bursts, whereas magnetic bottles are identified as the source of moving metric type IV radio bursts. The difference between the expansion speeds of these waves and bottles is examined during their generation and propagation near the flare regions. It is shown that, although generated in the explosive phase of flares, the behavior of the bottles is quite different from that of the waves and that the speed of the former is generally much lower than that of the latter.

It has been suggested that these waves are related to flare-associated interplanetary disturbances which produce SSC geomagnetic storms. These disturbances may, therefore, be identified as interplanetary shock waves. It is shown that the transit times of disturbances between the sun and the earth give information about the deceleration of shock waves to their local speeds observed near the earth's orbit. A brief discussion is given on the relationship among magnetic bottles, shock waves near the sun, and flare-associated disturbances in interplanetary space.

## Introduction

Many beautiful observations by the Culgoora radio heliograph have shown the moving patterns of the sources of both type II and type IV radio bursts at 80 $MH_z$ frequency (e.g., Wild, 1970; Smerd and Dulk, 1971; Wild and Smerd, 1972); they are useful to investigate the movement of these sources in the outer solar corona and its relation to interplanetary shock waves as observed at the earth's orbit or its vicinity. Since the emission mechanism is well known to be completely different for these two radio bursts (e.g., Kundu, 1965, Zheleznyakov, 1970), the difference between the moving patterns of these sources seems very important for investigating the generation and propagation of shock waves and magnetic bottles, both of which are generally generated in the same flares.

Recently, Schatten(1970) has concluded that the expansion speed of magnetic bottles is 200-300 km $sec^{-1}$ in the solar envelope and that, in general, these bottles do not expand beyond this envelope. By analyzing the relationship between the observed speeds of a magnetic bottle and shock waves near the sun and at the earth's orbit from the 4 November 1968 flare, the shock wave responsible for the type II burst was found, which propagated with the speed of 2000-3000 km $sec^{-1}$. This speed was much faster than that of the magnetic bottle, which expanded at $\simeq$ 200 km $sec^{-1}$. The mean speed of the interplanetary shock wave between the sun and the earth was 650 km $sec^{-1}$. Furthermore, Smerd and his colleagues. have found that the expanding patterns of type IV radio sources are usually different from those for moving metric type IV bursts (e.g., Smerd and Dulk 1971; Dulk et al., 1971). Their results also show that the expansion of type II sources is usually followed by type IV sources.

These results are very important for understanding the generation and propagation of these two sources and their relation to such phenomena as flare-associated interplanetary disturbances and SSC geomagnetic storms. In this paper, we shall investigate the relationships among these two radio sources and flare-associated interplanetary disturbances. In order to find such relationships, we shall first analyze the expansion speeds of both type II and type IV sources and then compare them with the observed data on interplanetary shock waves. Based on this study, we then discuss the generation and propagation of these sources in the solar envelope.

## 2. Type II and Type IV Sources Generated by Solar Flares

We have selected several events for which the flare start time, the flare position and importance, the time of the occurrence of SSC on earth, the average speed over 1AU, $V_{\bar{I}}$, and the shock speed at 1AU, $V_L$ are all known and given in Table I. The information concerning the type II and type IV radio bursts, the proton flares, and the estimated speeds for the sources of these radio bursts denoted by $V_I$ and $V_B$ respectively, is given in Table II. It is clear from this table that, in general, the speed of type IV sources is slower than that of type II sources: that is, shock waves generating type II bursts usually propagate faster than type IV sources in the solar atmosphere.

It is thought at present that these shock waves or shock induced disturbances propagate through the space between the sun and the earth and then, generate geomagnetic disturbance when they arrive at the earth or its vicinity (e.g., Obayashi, 1967). Therefore, the time difference between the flare start and the occurrance of SSC determines the propagation time of the disturbances from the sun to earth. Satellite records on the sudden change of the interplanetary magnetic field also gives important information about shock propagation times and their local speed near the earth. The mean speed $V_I$ of these waves or associated disturbances which are estimated from these times, are also summarized in Table I.

At present, the metric component of moving type IV radio bursts is explained as emission by gyro-synchrotron mechanism from mildly relativistic electrons due to their interaction with sunspot magnetic fields near the flare site. The movement of the type IV radio sources, therefore, suggests that the magnetic fields tend to move outward with the electrons; suggesting that electrons are being trapped by these magnetic fields while both of them are moving outward. The results summarized in Table I thus shows that the speed of motion of these field lines is less than that of shock waves responsible for type II bursts. As discussed by Smerd and Dulk (1971) and Sakurai (1973a), the source of moving metric type IV bursts is identified as the magnetic bottle consisting of sunspot magnetic field lines being stretched outward from the flare regions. Therefore, the difference between $V_{II}$ and $V_B$ strongly suggest that these bottles move independently of shock waves in the solar atmosphere after ejection from the flare regions.

Using these observed results, we shall consider the generation of both shock waves and magnetic bottles in solar flares and their propagation into outer space.

## 3. Generation and Propagation of Shock Waves and Magnetic Bottles in the Solar Atmosphere

As shown in Table II, the expansion speed of magnetic bottles i usually less than that of shock waves. Therefore, it seems likely that, in the solar atmosphere, the behavior of shock waves is quite different from that of magnetic bottles, as an example, consider the case of the flare of 4 November 1968. This flare was a major one which occurred at the west limb at ~0513 UT, producing various phenomena such as radio bursts of spectral type II, III, and IV, solar cosmic rays of Mev energy, interplanetary shock wave and SSC geomagnetic storm (see Lincoln, 1970; Sakurai, 1973b). Schatten (1970) estimated the average expansion speed of an associated magnetic bottle to be $\approx 200$ km sec$^{-1}$ in the solar envelope. In contrast to this speed, the propagation speed of a shock wave responsible for type II burst is estimated to be between 2000 and 3000 km sec$^{-1}$ (Sakurai et. al., 1973). Furthermore the mean propagation speed of the flare-associated interplanetary disturbances between the sun and the earth, was $\gtrsim$ 650 km sec$^{-1}$, much slower than the speed of the shock wave as the source of type II burst which suggests that the shock wave was slowed while propagating through interplanetary space. These three speeds are illustrated in Fig. 1, to show schematically the behavior of the shock waves and the magnetic bottle after the onset of the parent flare.

All other events described in Table I show similar behavior of shock waves and magnetic bottles to that shown in Fig. 1. The speed of expanding shock waves responsible for type II bursts is usually higher than that of magnetic bottles identified as the source of mov ng metric type IV bursts. At present, it is believed that both shock waves and magnetic bottles are generated during the explosive phase of solar flares (e.g., Smith and Harvey, 1971; Sakurai, 1973c). These bottles consist of heated plasma and high-energy protons and electrons. The electrons are identified as the source of moving type IV bursts, and are believed to be accelerated to mildly relativistic energies during the explosive phase. Sometimes these bottles are slowed down and cease to move radially beyond 10-15 solar radii, (Schatten, 1970; Sakurai, 1973d). Even if a bottle is ejected beyond the boundary of the solar envelope, it is expected that its arrival at the earth's orbit would be delayed by at least some tens of hours compared to the time of the shock arrival. If such a bottle is thought of as the source of the main phase of a geomagnetic storm, the time interval between the SSC and the main phase must be some tens of hours. We have never observed such a long time delay(see Akasofu and Chapman, 1971). We may suggest that the main phase is caused by the compressed turbulent plasma behind the interplanetary shock waves. The magnetic bottle may or may not expand into interplanetary space depending on the trapped energetic clouds are able or unable, respectively, to overcome the magnetic pressure. When the bottle is able to expand into interplanetary space, the plasma in front of the bottle may be the sources of the observed helium enriched plasma (e.g., Hirshberg et. al., 1972).

We see that both shock waves and magnetic bottles seem to be generated in the explosive phase of flares. However, there seem to be two possibilities for their generation; 1) shock waves are blast waves, being independent of the generation of magnetic bottles, 2) shock waves are generated by magnetic bottles if the latter move with a speed higher than the local Alfven waves immediately after their production in the explosive phase. In this case, these bottles must be assumed to be decelerated very quickly, say within a few minutes, after they generate shock waves. This may correspond to the case that the duration which shock waves are driven is very short, as discussed by Hundhausen and Gentry (1969).

In the first case, magnetic bottles must be produced independently of the generation of shock waves. In order to explain the slow speed expansion of these bottles, we suggest that their formation is related to the acceleration of high-energy protons and electrons because, in general, the emission of moving type IV bursts is observed in association with proton flares; these protons are released in outer space as solar cosmic rays (Sakurai, 1969). In this case, it seems likely that the expansion of such bottles ceases finally because of the energy loss of high-energy electrons and of bottle's adiabatic expansion.

## 4. Interplanetary Shock Waves as Observed at the Earth's Orbit

It seems that shock waves responsible for type II bursts are related to the interplanetary shock waves observed at the earth's orbit and its vicinity. By using the time difference between solar flares and the magnetic field variations observed on earth and by satellites, the mean speed of the interplanetary disturbances propagating between the sun and the earth can be estimated. Furthermore, we may estimate the local speed of shock waves near the earth by using the time differences between the observations at the earth and at satellites or by using the measured plasma and magnetic field data. These speeds thus estimated are shown in Tables I and II. Although the number of the observations is not large, we can conclude that the mean speed ($V_I$) is usually higher than the local speed for every case except for the 4 Feb, 1967 event.

Furthermore, the result in Tables I and II shows that the mean speed of interplanetary disturbances is always smaller than the speed of the source of type II burst. If we postulate that the shock wave generated near the sun can propagate continuously through interplanetary space, we can describe the variation of its speed through this space.

The observations described above suggest that shock waves are strongly decelerated while propagating through interplanetary space. Hundhausen and Gentry (1969) have shown that such deceleration really occurs for a blast-wave type of shock wave propagating through the space between the sun and the earth.

On the other hand, if the shock wave observed near the sun is unable to propagate for a distance comparable to 1 A.U., the interplanetary shock wave as observed at the earth has to be generated in interplanetary space. Then the flare-ejecta may be the agent which can produce those shock waves observed near the earth. A detailed description of such a model will be given in the near future.

## 5. Summary

In this paper, we have considered the relationships among the speeds of type II and type IV radio sources and flare-associated interplanetary disturbances, all of which are generated by the same solar flares. These interplanetary disturbances are usually observed as shock waves. We suggest that the source of type II bursts tends to propagate independently of that of type IV bursts in the solar atmosphere; their speeds are much different from each other. This suggests that, even though these two sources are produced simultaneously in the explosive phase of a flare, their behavior is quite different in the solar atmosphere after they form at the flare site. We have considered two possible models for the generation of these sources during the explosive phase, but it seems premature to conclude which one is more favorable to explain the observations.

The shock waves responsible for type II radio bursts seem to be related to interplanetary shock waves as observed at the earth's orbit. The observed difference between the speeds of these two shock waves suggests that, while propagating through interplanetary space, these waves are decelerated sharply from one or two thousand km $sec^{-1}$ to several hundred km $sec^{-1}$ if they propagate continuously through space. The observation of the local speed of interplanetary shock waves shows that this deceleration occurs somewhere between the sun and the earth.

It should be noted that the magnetic bottles discussed in this paper cannot be the sources of the main phases of geomagnetic storms because they are not identified as the post-shock plasma. In fact, the slow speed expansion of these bottles cannot explain the progress of geomagnetic storm because of the estimated time delay of some tens of hours of their arrival after the onset of SSC at the earth.

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TABLE I

The average and local speeds of interplanetary disturbances

| SOLAR EVENTS | UT | FLARE POSITION | IMP | SSC UT | $V_I$ (km sec-1) | $V_L$ |
|---|---|---|---|---|---|---|
| 20 Sept. 1963 | 2350 | N10W09 | 2B | 22 Sept. 1550 | 1040 | no data |
| 7 July 1966 | 0023 | N34W48 | 2B | 8 July 2100 | 920 | 750 |
| 28 Aug. | 1522 | N23E04 | 3B | 30 Aug. 1112 | 940 | no shock |
| 4 Feb. 1967 | 1640 | N11E40 | 2B | 7 Feb. 1640 | 580 | 700 |
| 23 May | 1835 | N28E24 | 3B | 25 May 1240 | 960 | 540 |
| 4 Sept. 1968 | 0100 | N13W14 | 1N | 6 Sept. 1400 | 670 | 640 |
| 23 Oct. | 2355 | S12E59 | 3B | 26 Oct. 1833 | 630 | no data |
| 26 Oct. | 0130 | S20E32 | 1N | 29 Oct. 0908 | 520 | 420 |
| 4 Nov. | 0513 | S15W90 | 2B | 6 Nov. 2000 | 660 | no data |
| 22 Nov. | 0056 | S16E39 | 1N | 24 Nov. 1600 | 660 | no data |
| 1 Mar. 1969 | 2213 | N08W89 | 1N | 4 Mar. 1836 | 610 | no shock |

TABLE II

The source speeds of type II and type IV bursts

| | II (radio | IV bursts) | Protons (Mev) | $V_{II}$ (km sec$^{-1}$) | $V_B$ | Ref. |
|---|---|---|---|---|---|---|
| 1963 Sept. 20 | yes | yes | yes | ~1500 | | a) |
| 1966 July 7 | yes | yes | yes | (>940) | 380 | b), c) |
| Aug. 28 | yes | yes | yes | ~1000 | <700 | k) |
| 1967 Feb. 4 | yes | yes | no | >750 | | a) |
| May 23 | yes | yes | yes | 1060 | ~500 | a), l) |
| 1968 Sept. 4 | yes | yes | no | 1350 | 780 | d) |
| Oct. 23 | yes | yes | yes | 3100 | 1400 | d), e) |
| Oct. 26 | yes | yes | no | >520 | 480 | d), f) |
| Nov. 4 | yes | yes | yes | ~2500 | 200 | g), h) |
| Nov. 22 | yes | yes | no | 2000 | 300 | i) |
| 1969 Mar. 1 | yes | yes | yes | 1080 | 270 | d), j) |

References

a) Smith and Harvey (1971)
b) Sakurai (1971)
c) Warwick (1969)
d) Smerd and Dulk (1971)
e) Kai (1969)
f) Kai et al. (1970)
g) Schatten (1970)
h) Sakurai (1973a )
i) Wild (1969)
j) Pinter (1973)
k) Dodson and Hedeman (1968)
l) Hirshberg et al. (1972)

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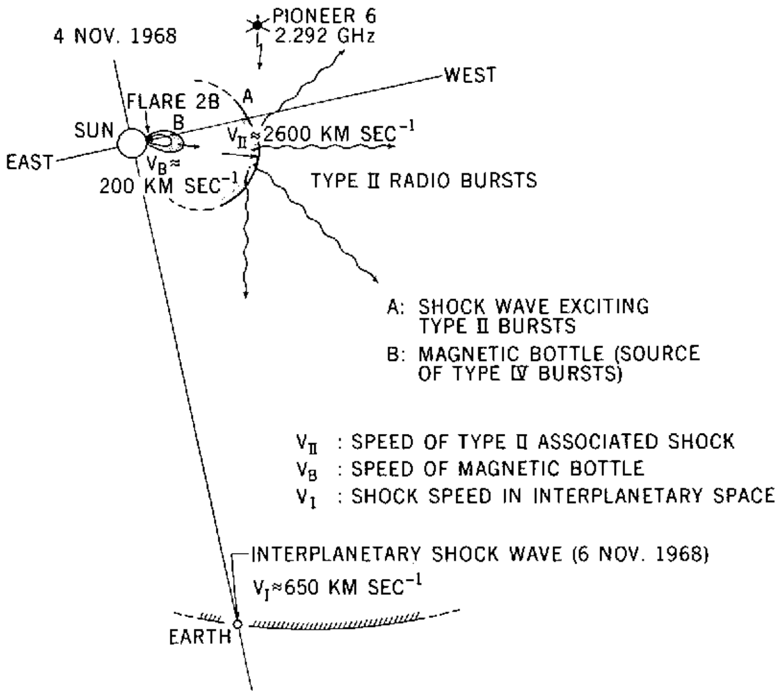


Fig. 1 Propagation of shock wave and magnetic bottle from the flare region in the case of 4 November 1968 proton flare. Two days later, interplanetary shock wave was observed on 6 November at the earth's orbit. These flare-associated disturbances are described in this pictures.